Coma cluster

A sharp view of the Coma cluster using uGMRT

Dharam V. Lal, NCRA-TIFR

with due thanks to
Ishwara-Chandra C.H., Venturi T.
staff of GMRT, …

GMRT upgrade

uGMRT is a major upgrade of the GMRT

- **The fundamental goal is to improve**
  - **major observational capabilities of the original GMRT (bandwidth, UV-coverage, sensitivity).**
- **This is a leveraged project - built upon existing infrastructure of the GMRT.**
- **Nearly seamless frequency coverage from 125 MHz to 1450 MHz**
  - **provided by 4 frequency bands**
  - **with new receivers.**
- **New correlator with 400 MHz bandwidth capability.**
  - **New digital / analog design to maximise instrumental stability and repeatability.**
- **Expectation - noise-limited, full-field imaging in all Stokes parametres for most observing fields.**
- **The project is scheduled to be completed by the end of 2017. ("uGMRT summary" talk)**

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What would we learn?

Faint synchrotron radiation is an indicator of wide spread B-field

=> we study, both,

- feedback of outflows driven by galactic BHs and

- the gravitationally driven evolution of large-scale cosmic filament structure.

=> highlights the potential to use diffuse synchrotron emission to illuminate ICM energisation in both clusters and lower density regions invisible at other wavelengths.

Archetype Coma cluster in the nearby universe!

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Prior knowledge | Coma cluster

352 MHz, WSRT image:134 x 68 arcsec^2 (Brown & Rudnick 2011)

408 MHz, DRAO+Arecibo: ~135 arcmin radio 'cloud' (Kronberg+ 2007)

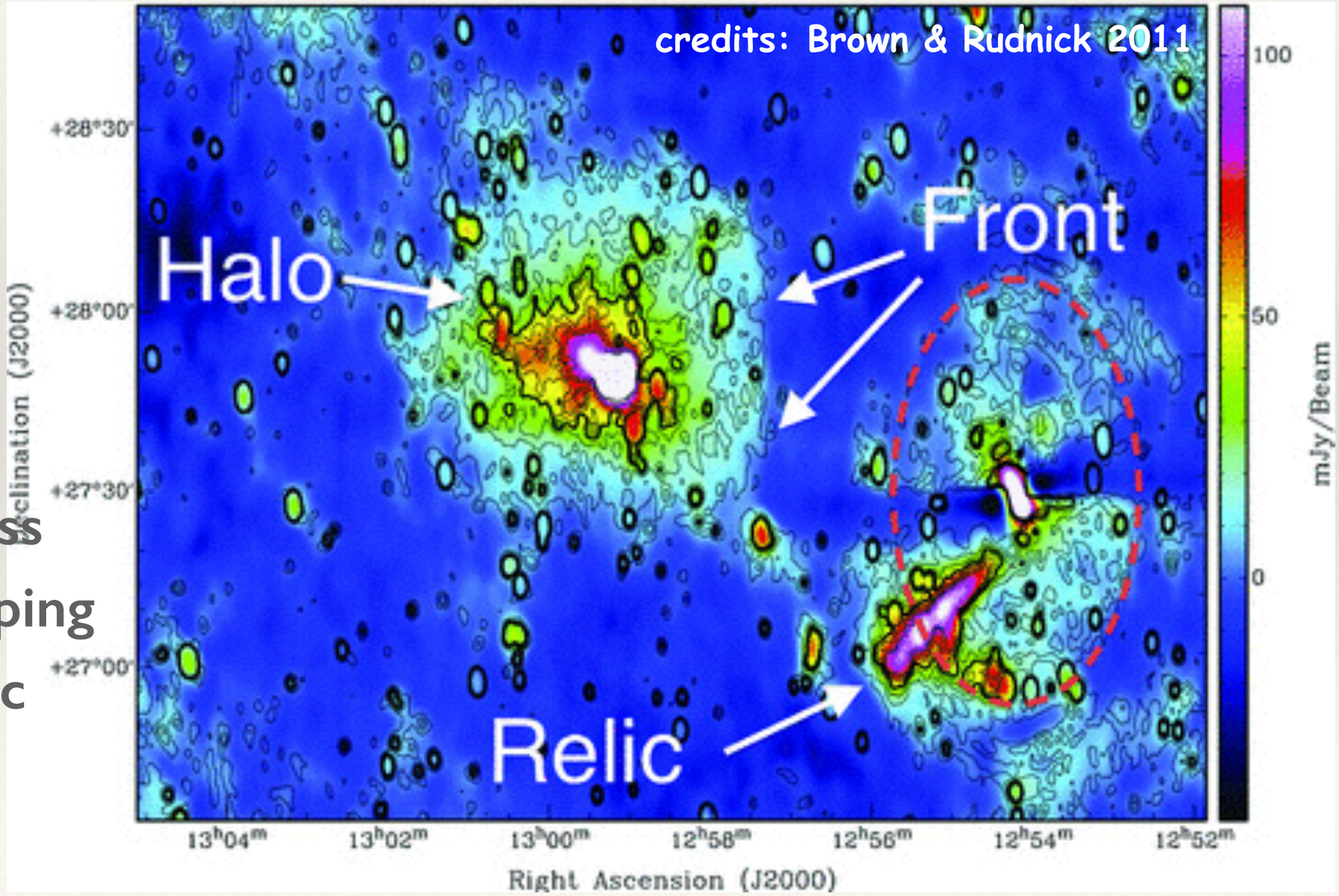
150 MHz, WSRT: radial steepening of spectral index (Pizzo 2010)

Abell 1656

z = 0.0235

469 pc/arcsec

existence of low surface brightness emission enveloping the halo and relic (Kronberg+ 2007)



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What images do we need?

Deep images containing all information on all spatial scales,

information of bright / faint point-sources,

information of low-surface brightness diffuse emission,

(information of polarisation structure)

…

We want to

high-fidelity images in all Stokes as a function of frequency

- fidelity: best high-dynamic range images

- and noise as low as ~ μJy levels.

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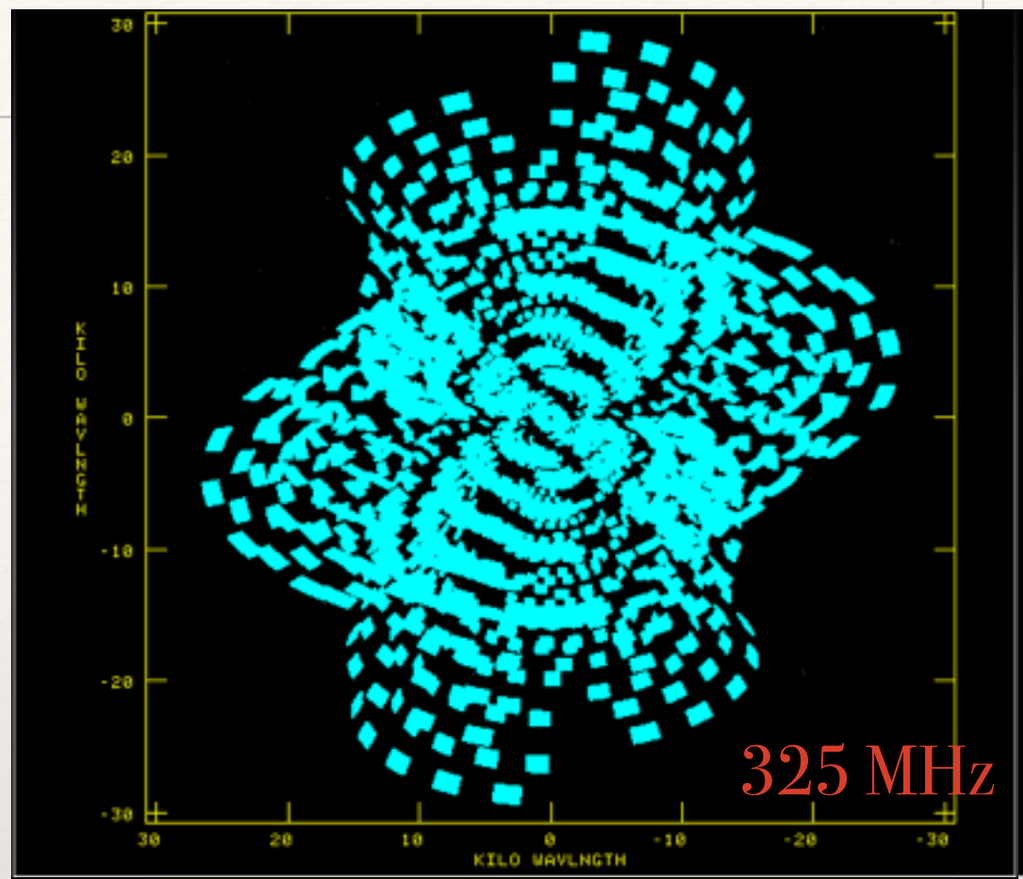
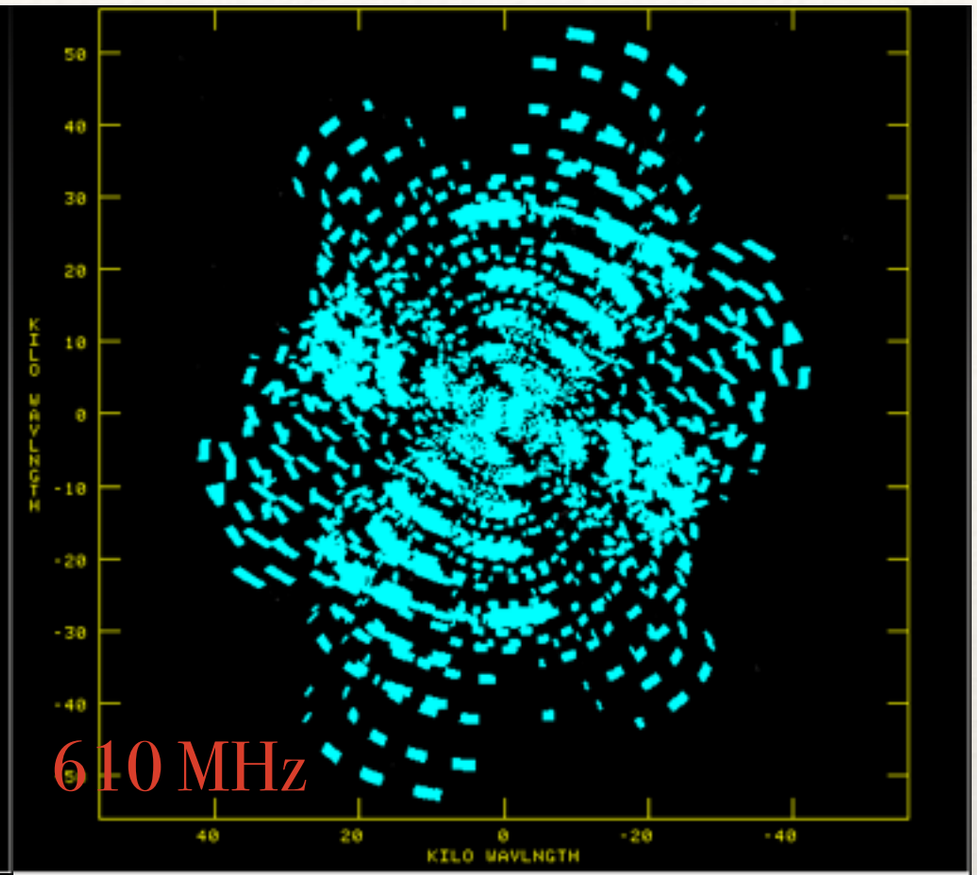
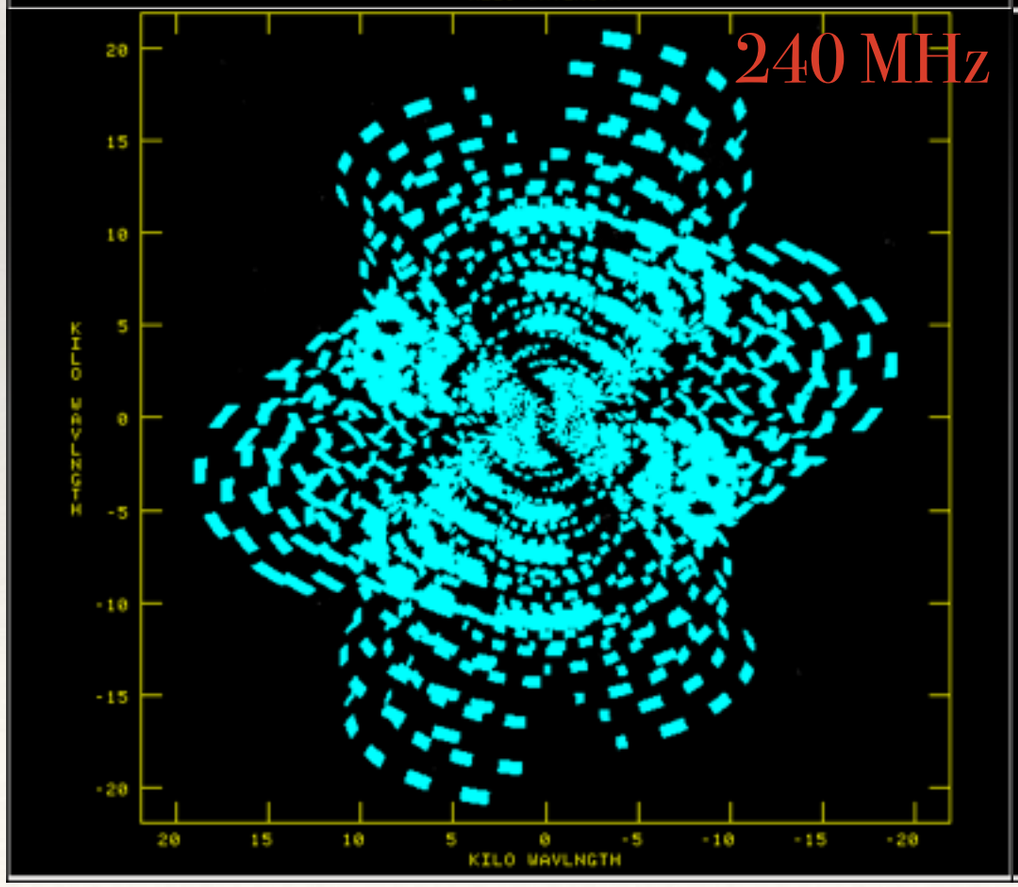
GMRT



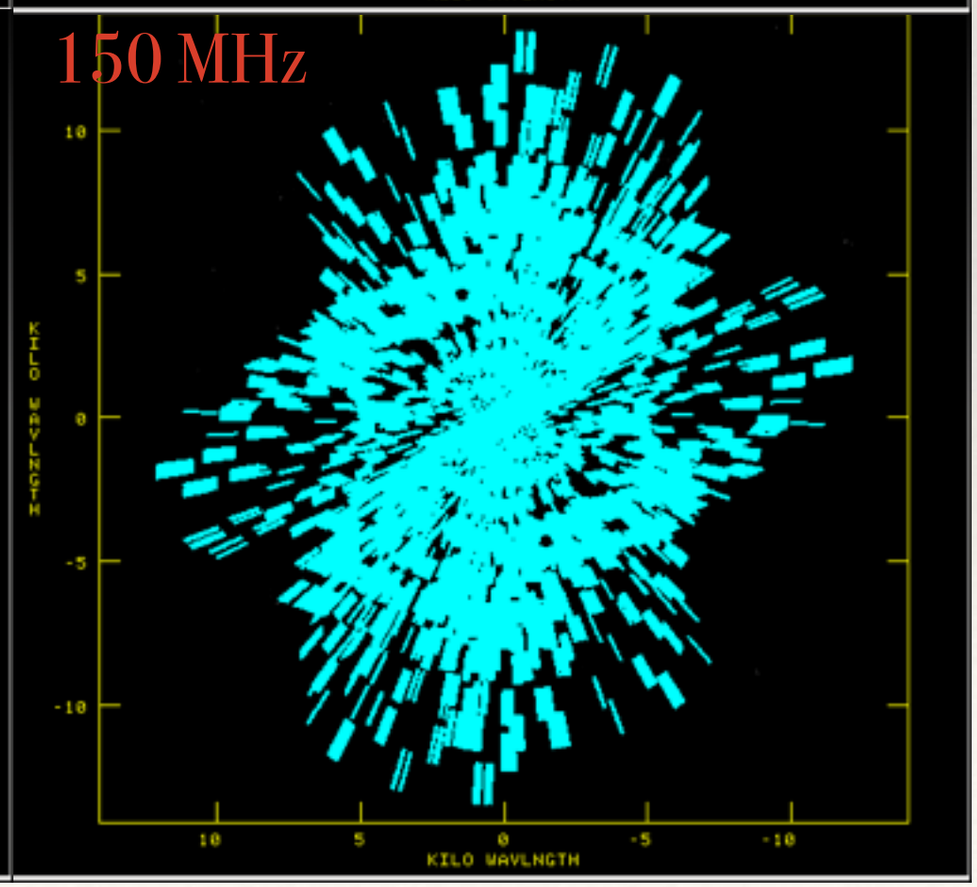
325 MHz



610 MHz



240 MHz



150 MHz

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GMRT: D

No. of antennas

26-28

No. of pol'n

1-2

No. of channels

64-256

Band-width

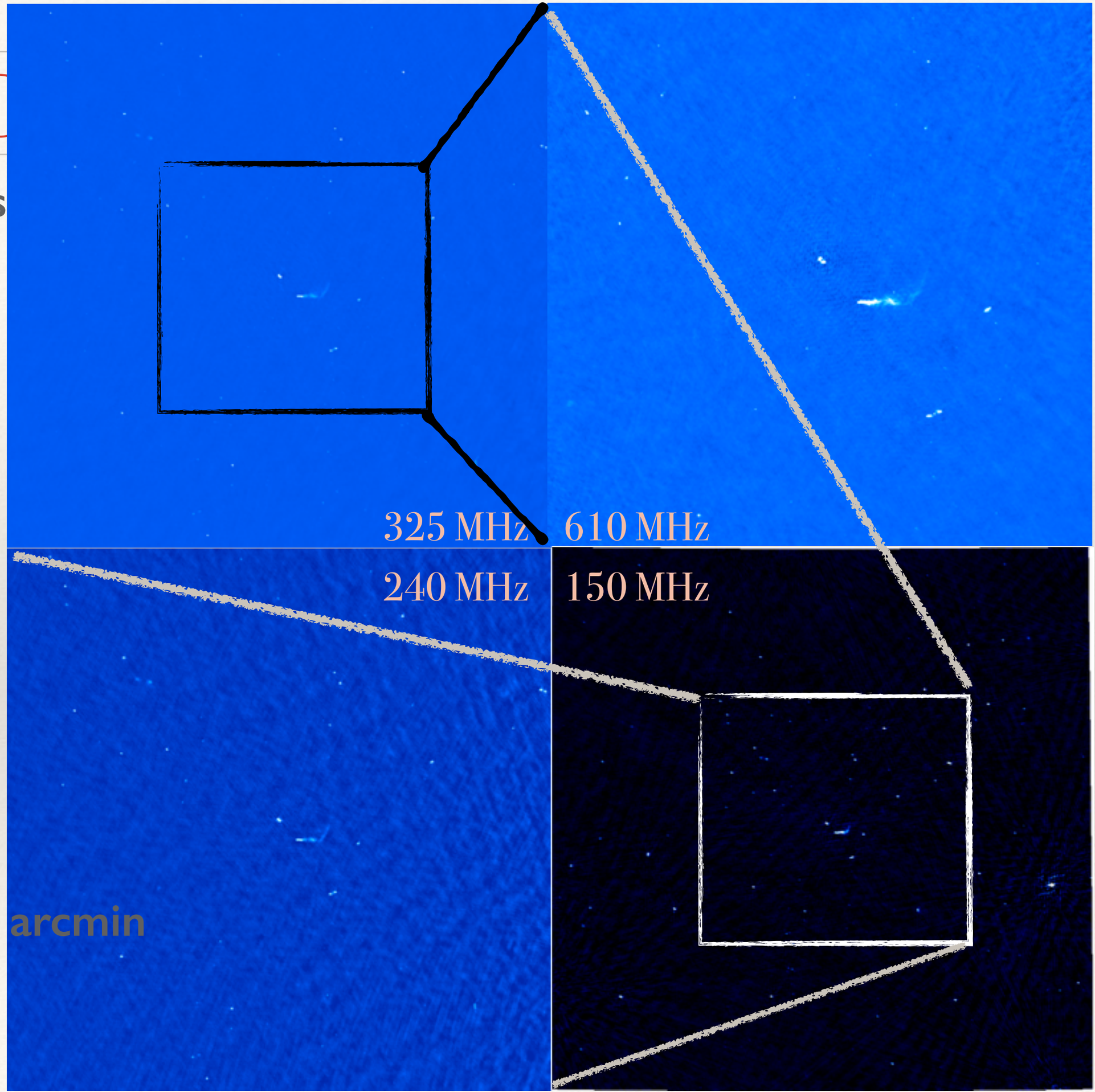
7-15 MHz

t_{int} (on-source)

2.0 - 2.5 hr

FoV

43/81/114/186 arcmin



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GMRT: Data reduction | 610 MHz

Shown here - 610 MHz

27 antennas

128 channels

15.0 MHz bandwidth

5 x 30 min (1 pol.)

FoV 43 arcmin

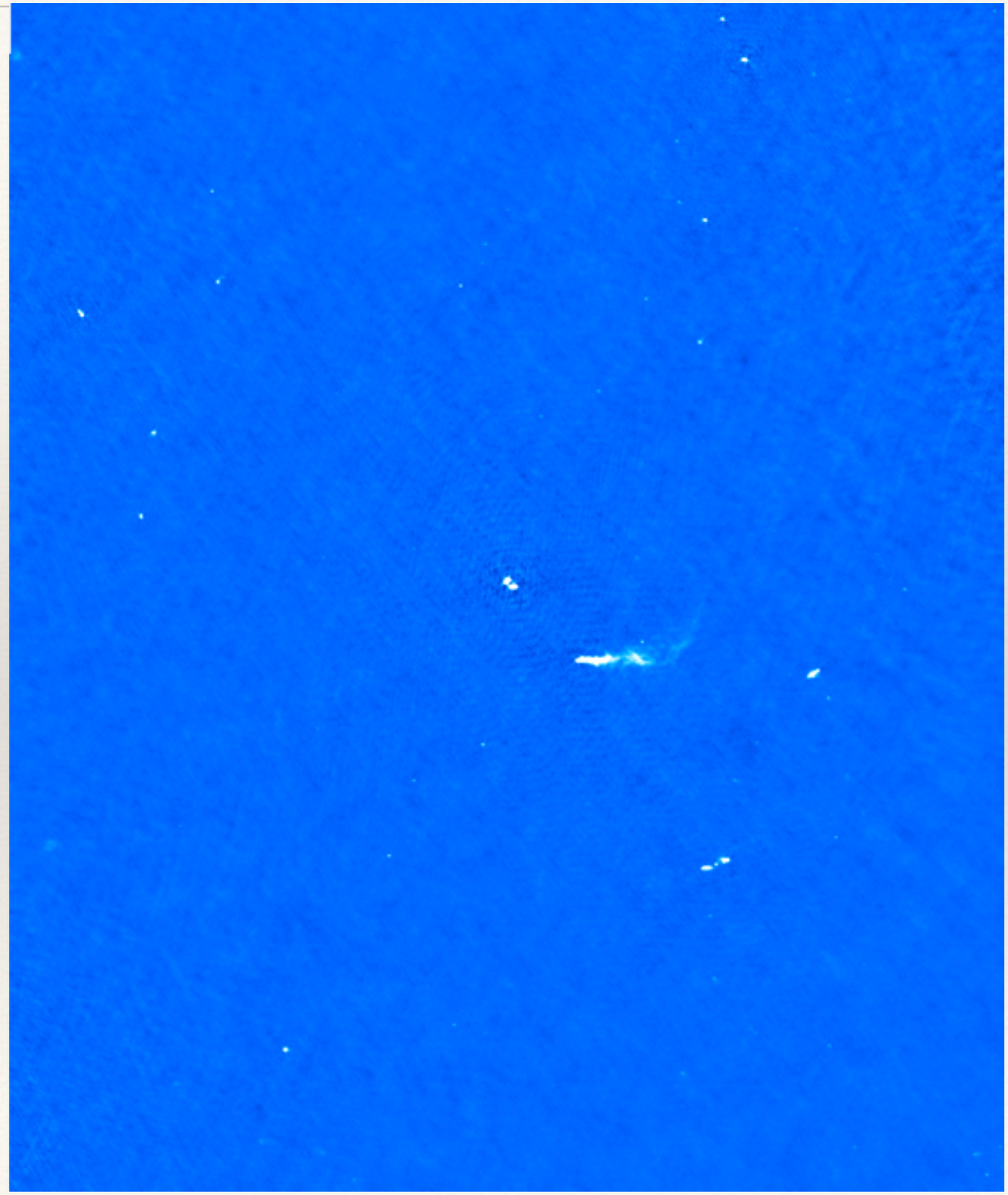
DR ~ 716

RMS noise

~0.1 mJy/beam

~4.9 arcsec beam

this is ~3 x thermal



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GMRT: Data reduction | 325 MHz

Shown here - 325 MHz

28 antennas

128 channels

14.8 MHz bandwidth

4.5 x 40 min (2 pol.)

FoV 81 arcmin

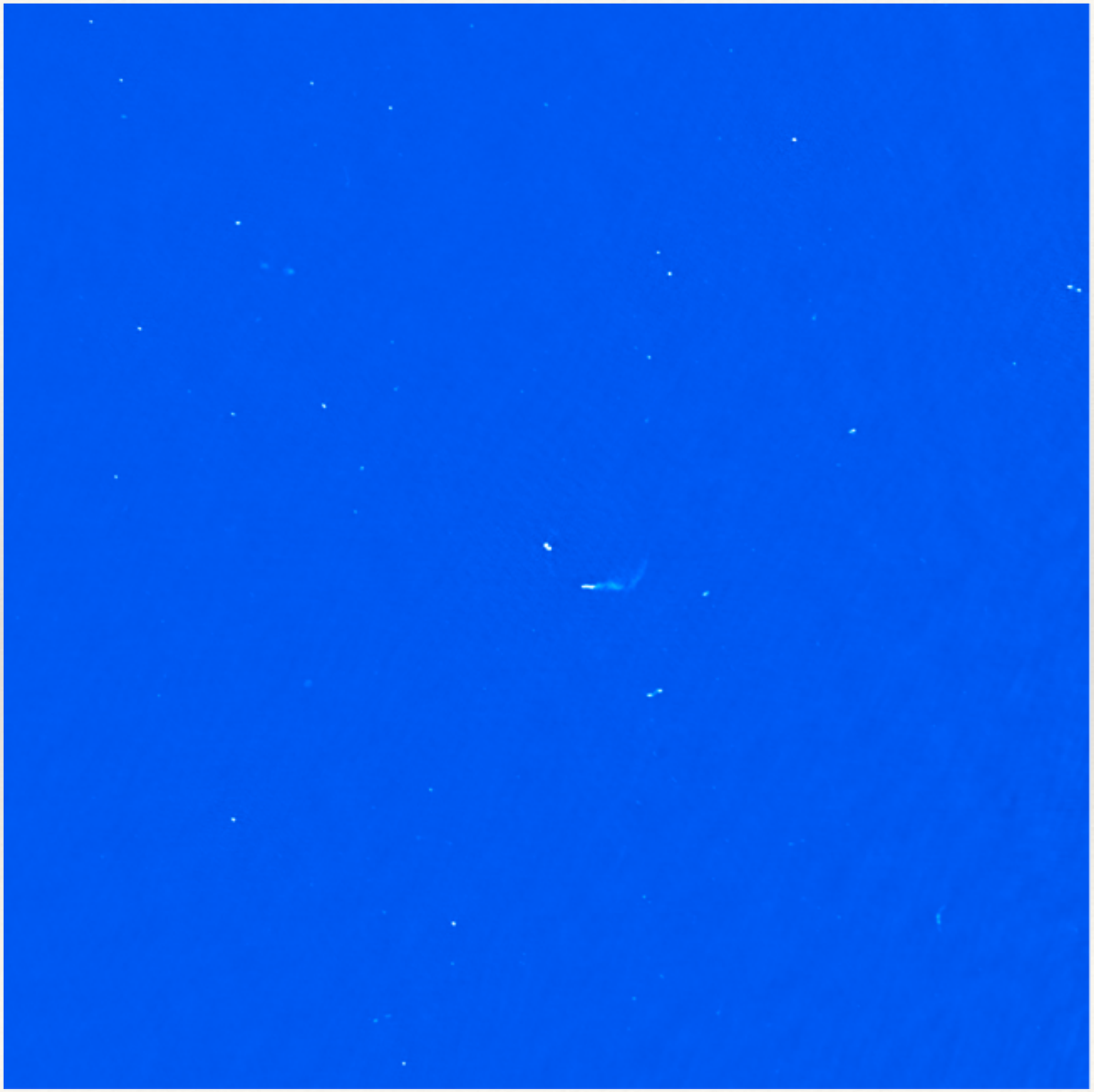
DR ~ 653

RMS noise

~0.35 mJy/beam

~8 arcsec beam

this is ~9 x thermal



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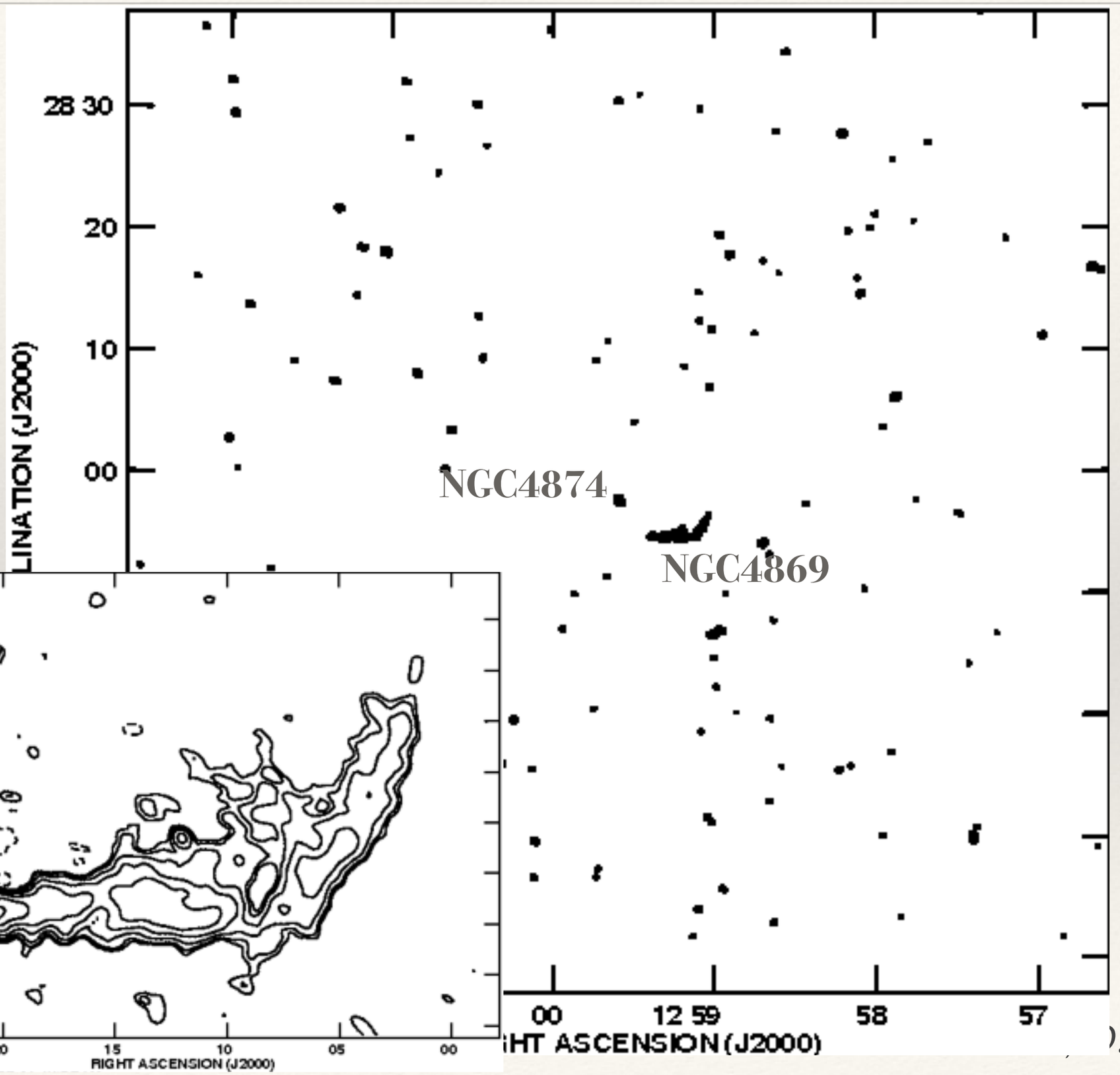
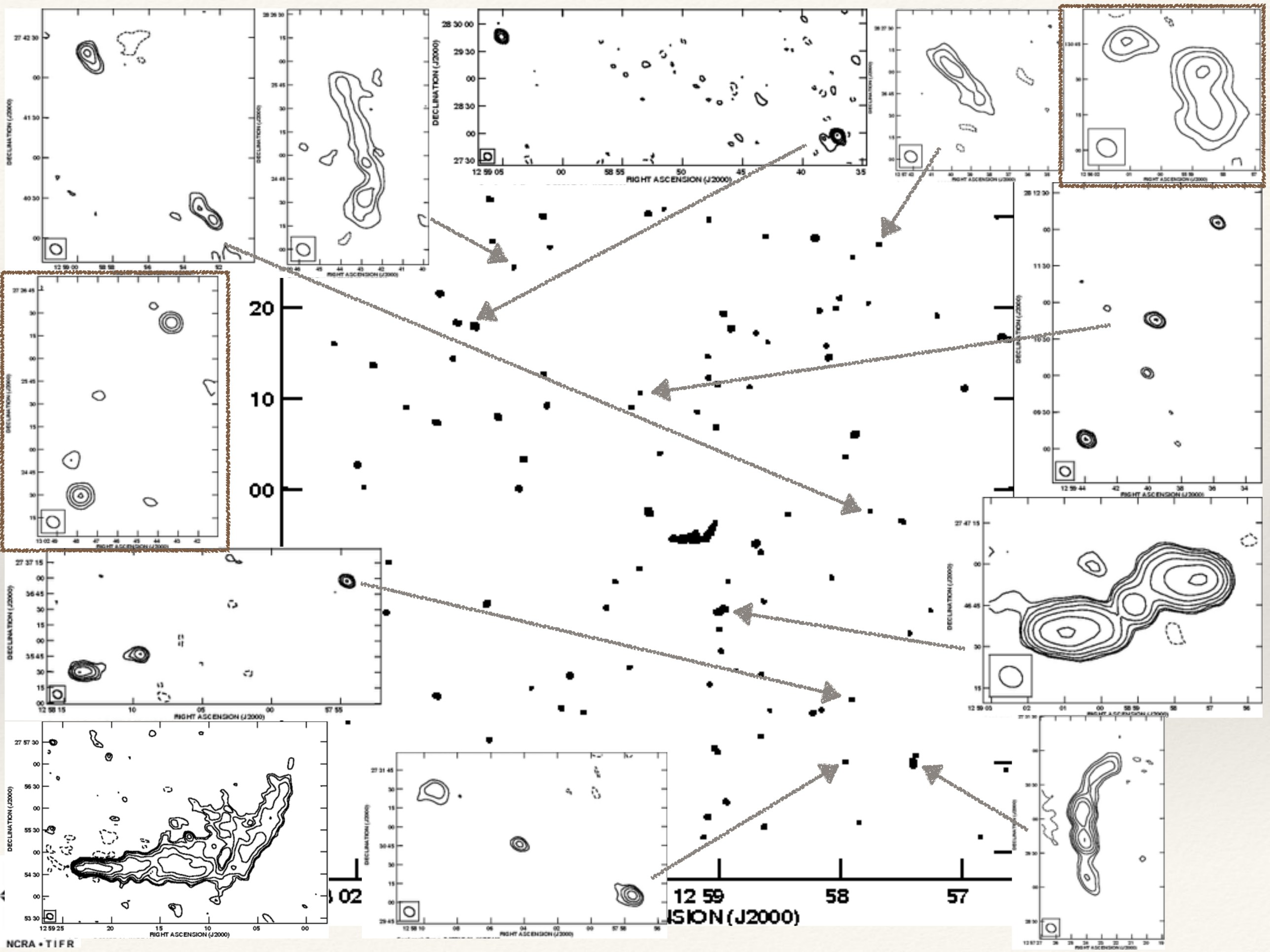
GMRT: Data reduction | 325 MHz



.V. ; SPARCS 2017


DECLINATION (J2000)
RIGHT ASCENSION (J2000)
20
10
00
12 59
58
57
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GMRT: Data reduction | 240 MHz

Shown here - 240 MHz

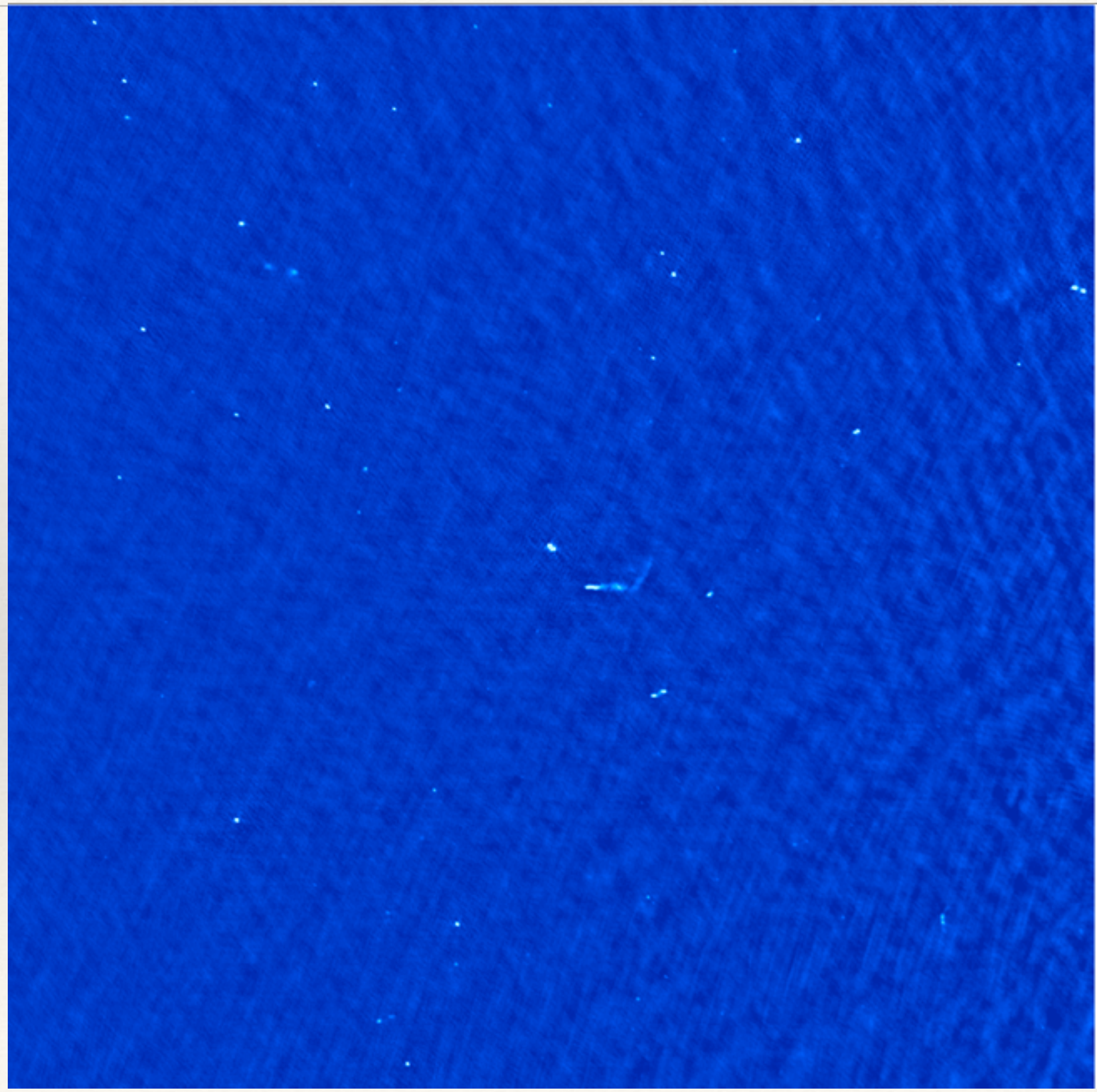
- 26 antennas
- 64 channels
- 5.2 MHz bandwidth
- 5 x 30 min (1 pol.)
- FoV 114 (81) arcmin

DR ~ 295

RMS noise

- ~1.1 mJy/beam
- ~10.8 arcsec beam

this is ~7 x thermal



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GMRT: Data reduction | 150 MHz

Shown here - 150 MHz

27 antennas

128 channels

14.2 MHz bandwidth

7 x 20 min

FoV 186 (177) arcmin

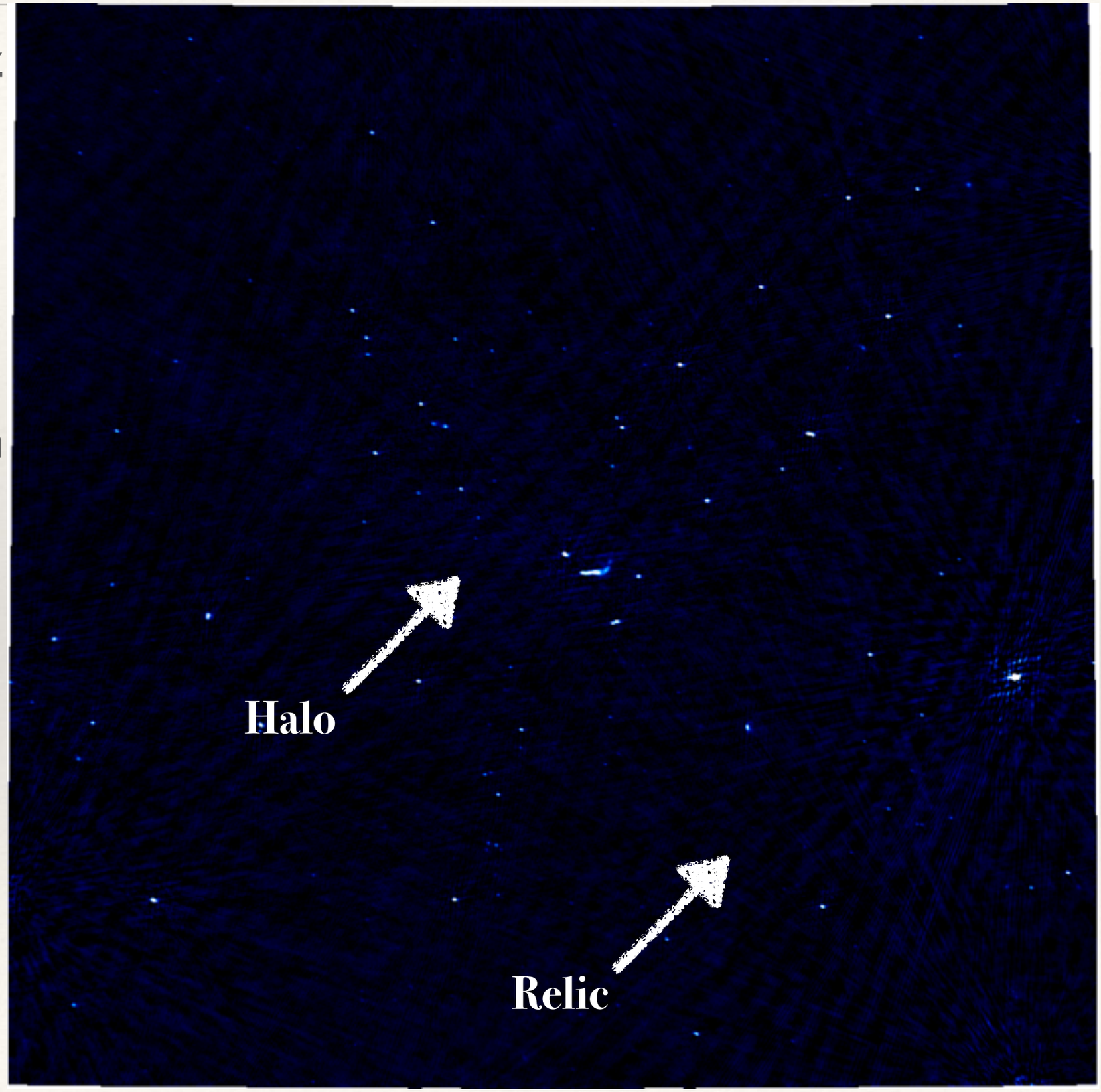
DR ~ 678

RMS noise

~5.4 mJy/beam

~21.8 arcsec beam

this is ~20 x thermal



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GMRT: Data analysis

Thanks to large field-of-view, high sensitivity, high resolution!

- **~30 radio galaxies that are associated with Coma,**
- **2 of them for the first time,**
- Kim et al. 1994 **lists all sources.**
- **…**

Next, if we account for all these sources, subtract these out then we should detect the diffuse (extended halo) emission.

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GMRT: Data analysis | 150 MHz

Thanks to large field-of-view, high sensitivity, high resolution!

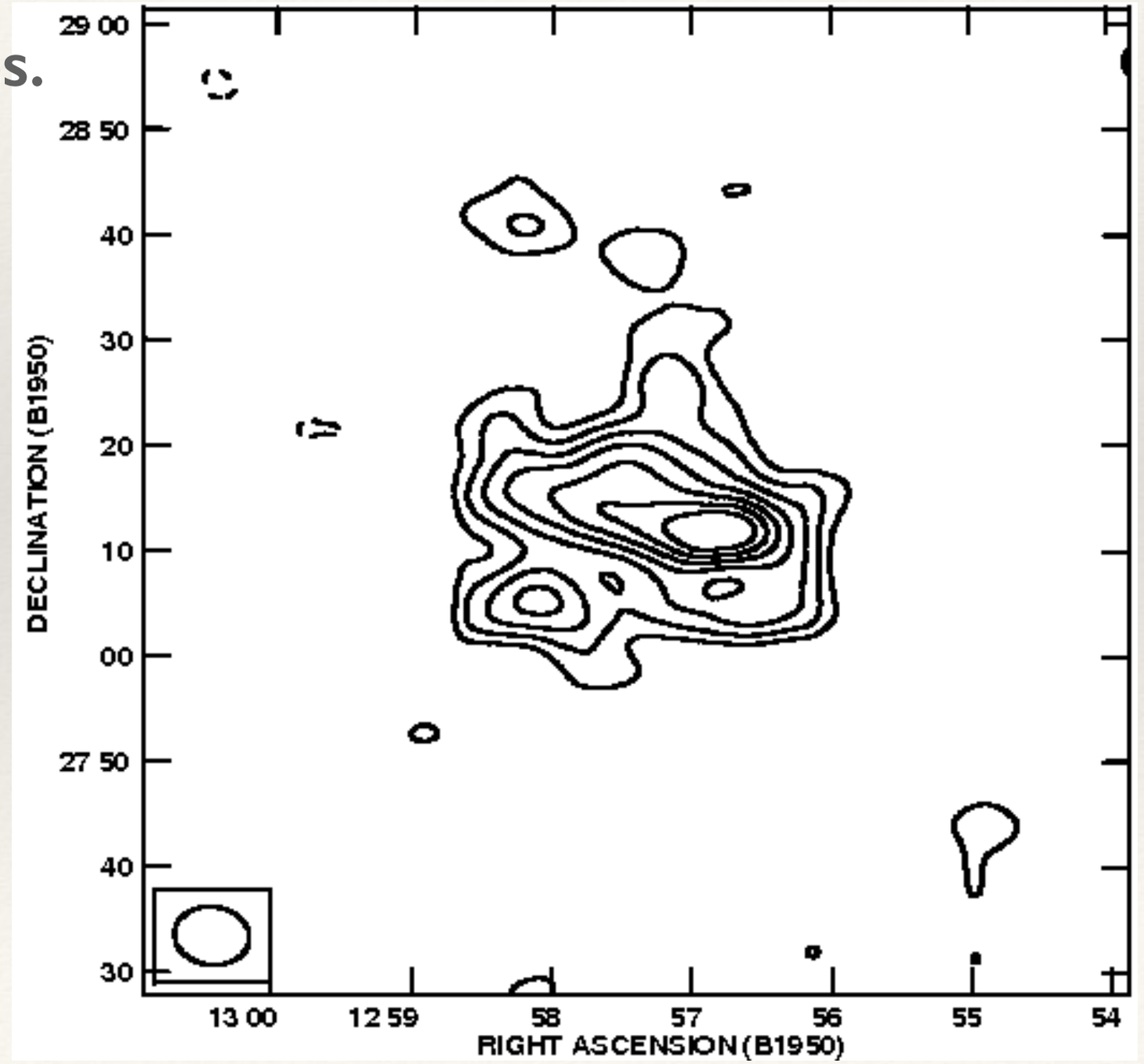
- **~30 radio galaxies that are associated with Coma,**
- **2 of them for the first time,**
- Kim et al. 1994 **lists all sources.**

- **150 MHz**

  ~50 arcmin extent

  9.8 +/- 0.3 Jy

  $\alpha_{(408-150)}$ 0.77 +/-0.08



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u-GMRT: Looking deeper | 250-500 MHz

Shown here - an early test of GWB

250-500 band synthesis on Coma

16 antennas

2048 channels

198.2 MHz bandwidth

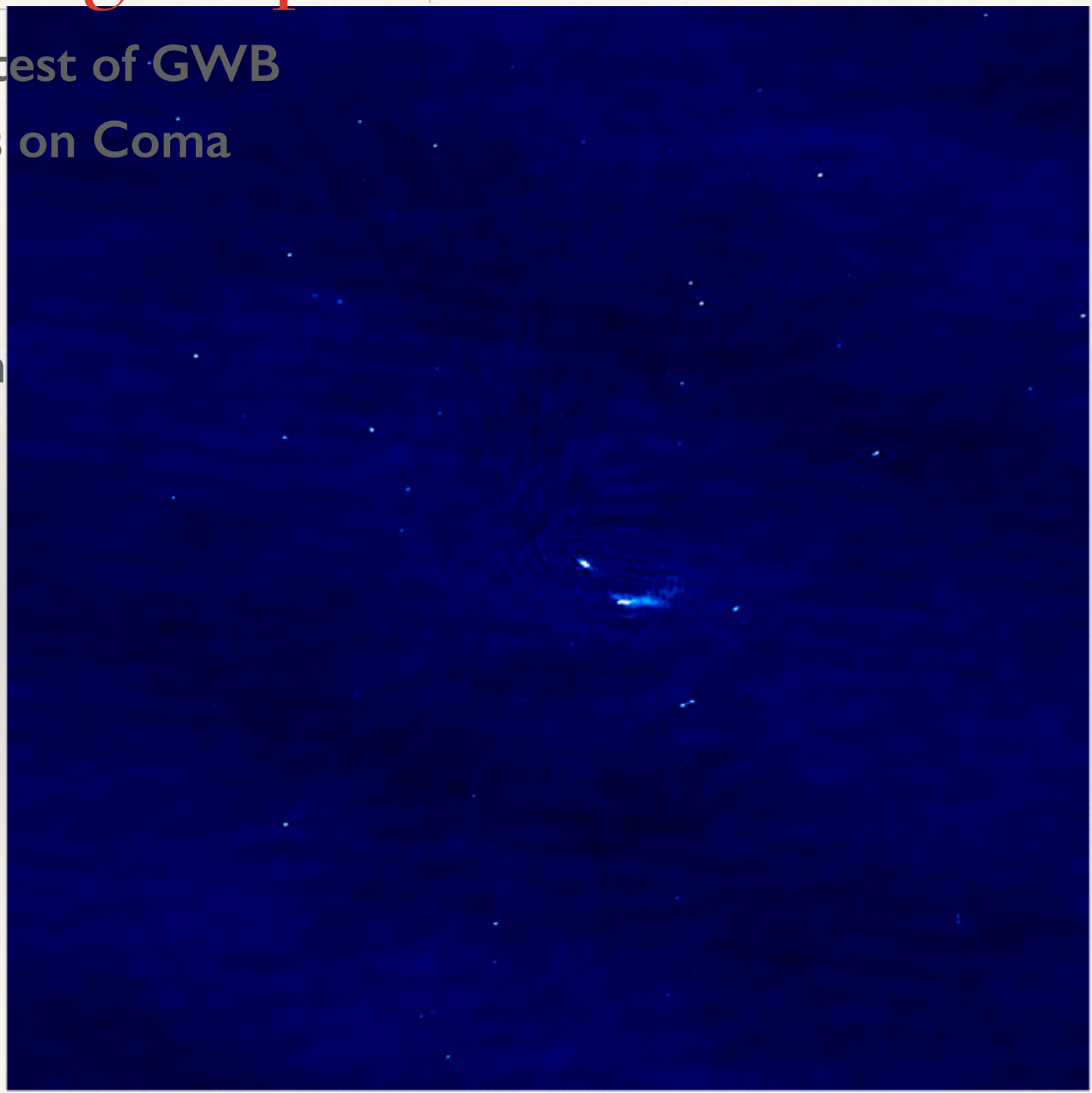
9 x 30 min

DR ~327

RMS noise

~0.3 mJy/beam

this is ~22 x thermal



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u-GMRT: Looking deeper | 250-500 MHz

Shown here - GWB

300-500 band synthesis

27 antennas

2048 channels

200 MHz bandwidth

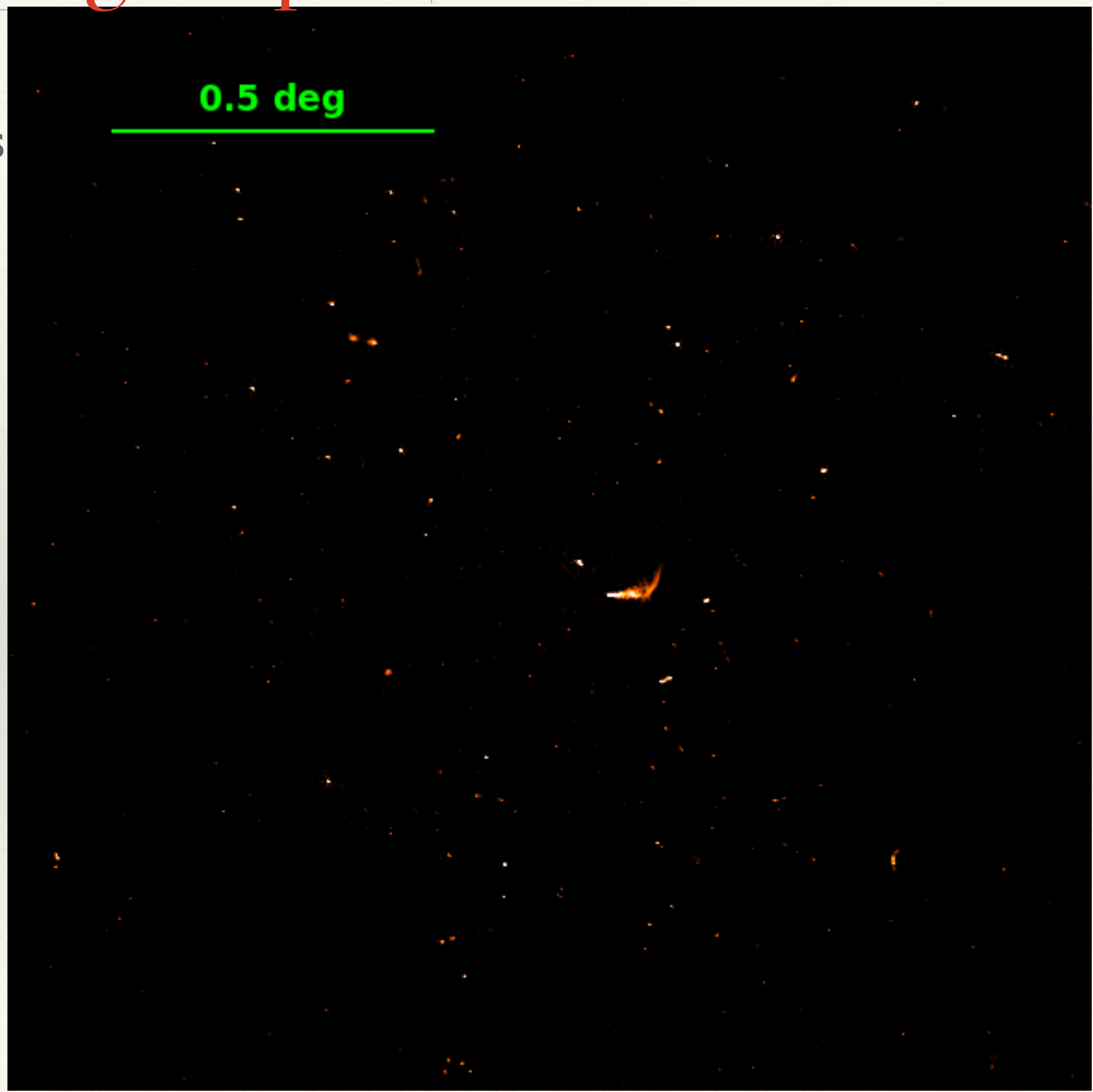
8 x 30 min

DR ~3500

RMS noise

~0.03 mJy/beam

this is ~5 x thermal



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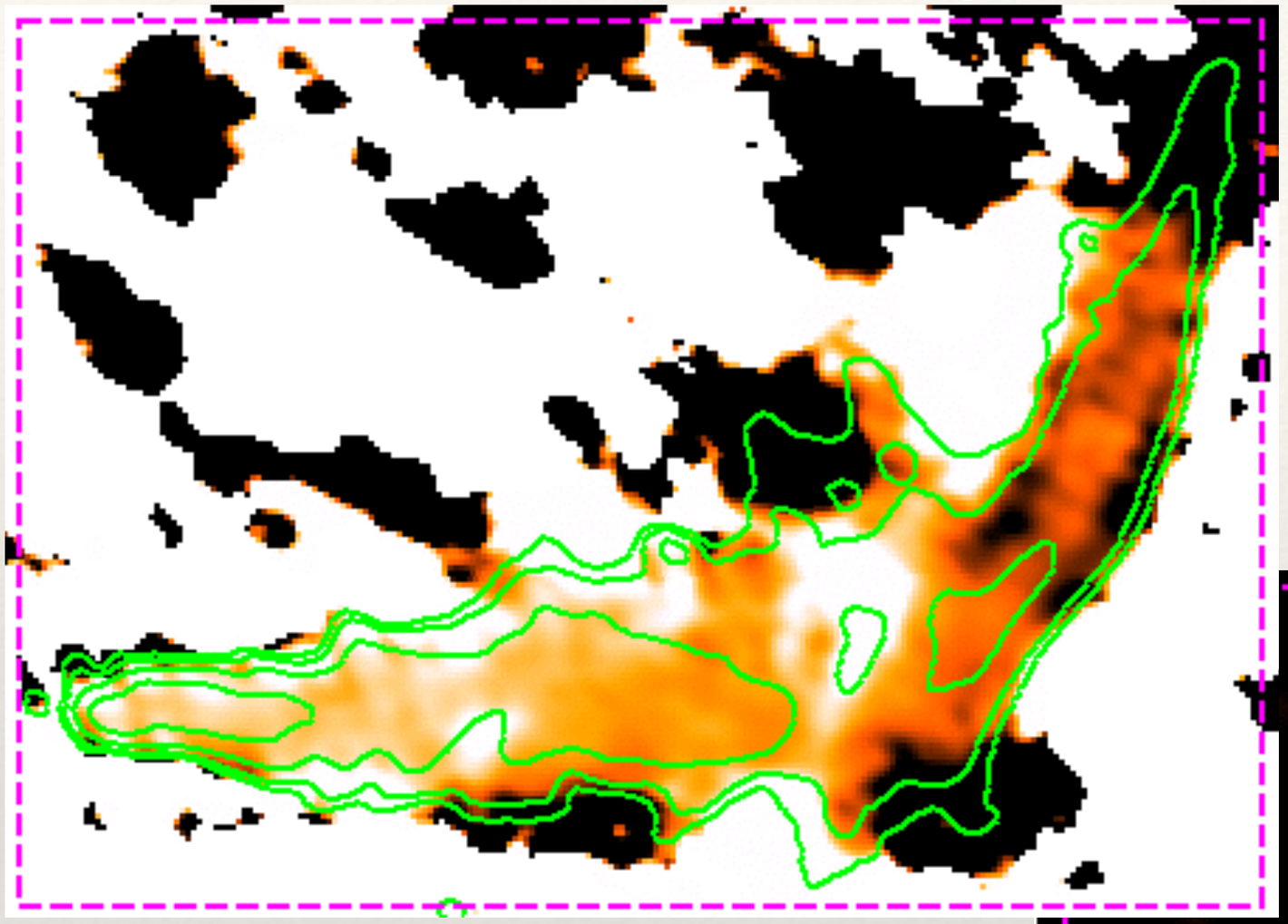
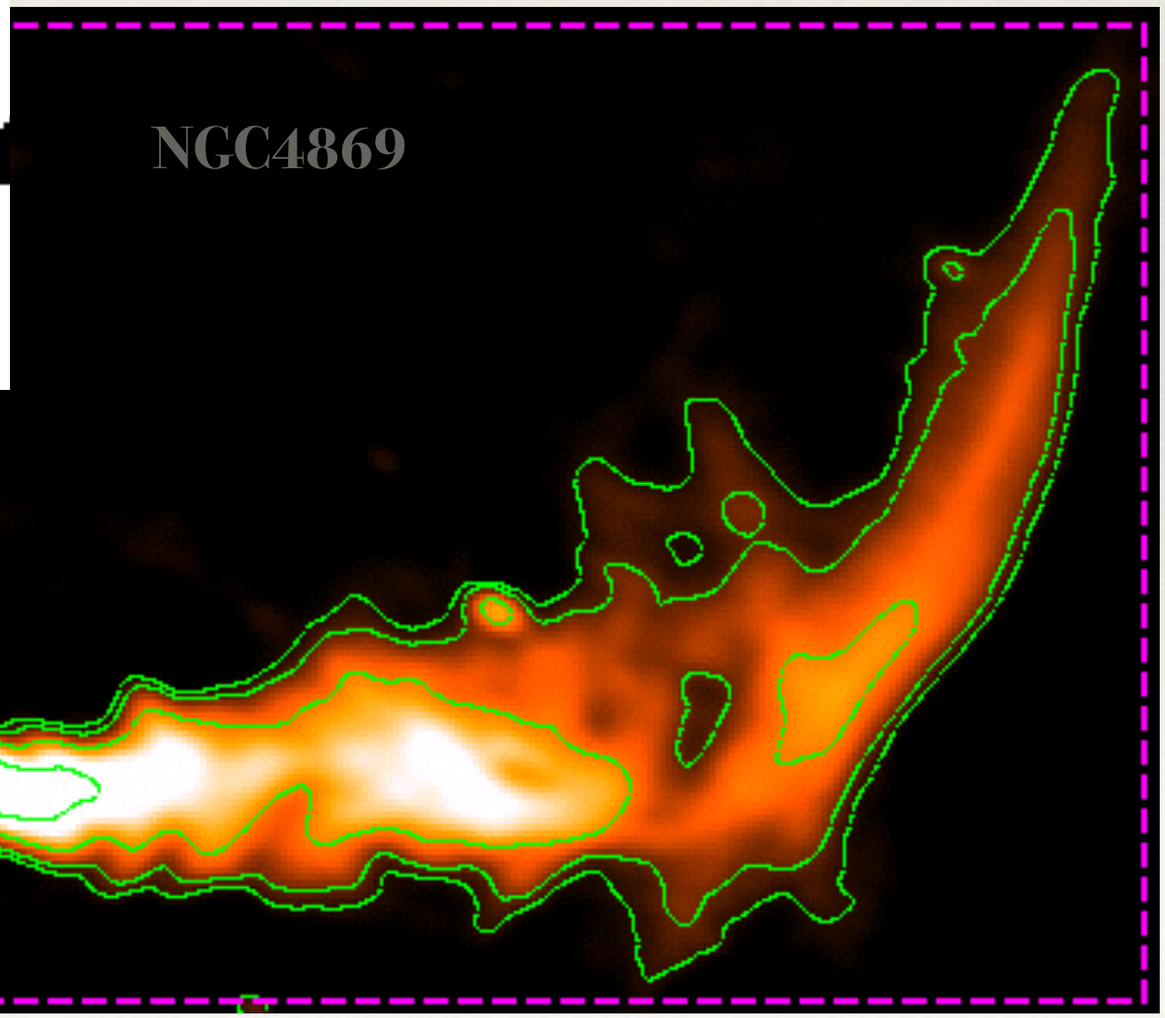
u-GMRT: Looking deeper | 250-500 MHz





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Halo emission | Coma cluster

Thanks to large field-of-view, high sensitivity, high resolution!

- **~30 radio galaxies that are associated with Coma,**
- **2 of them for the first time,**
- Kim et al. 1994 **lists all sources.**

- **150 MHz**

  ~50 arcmin extent

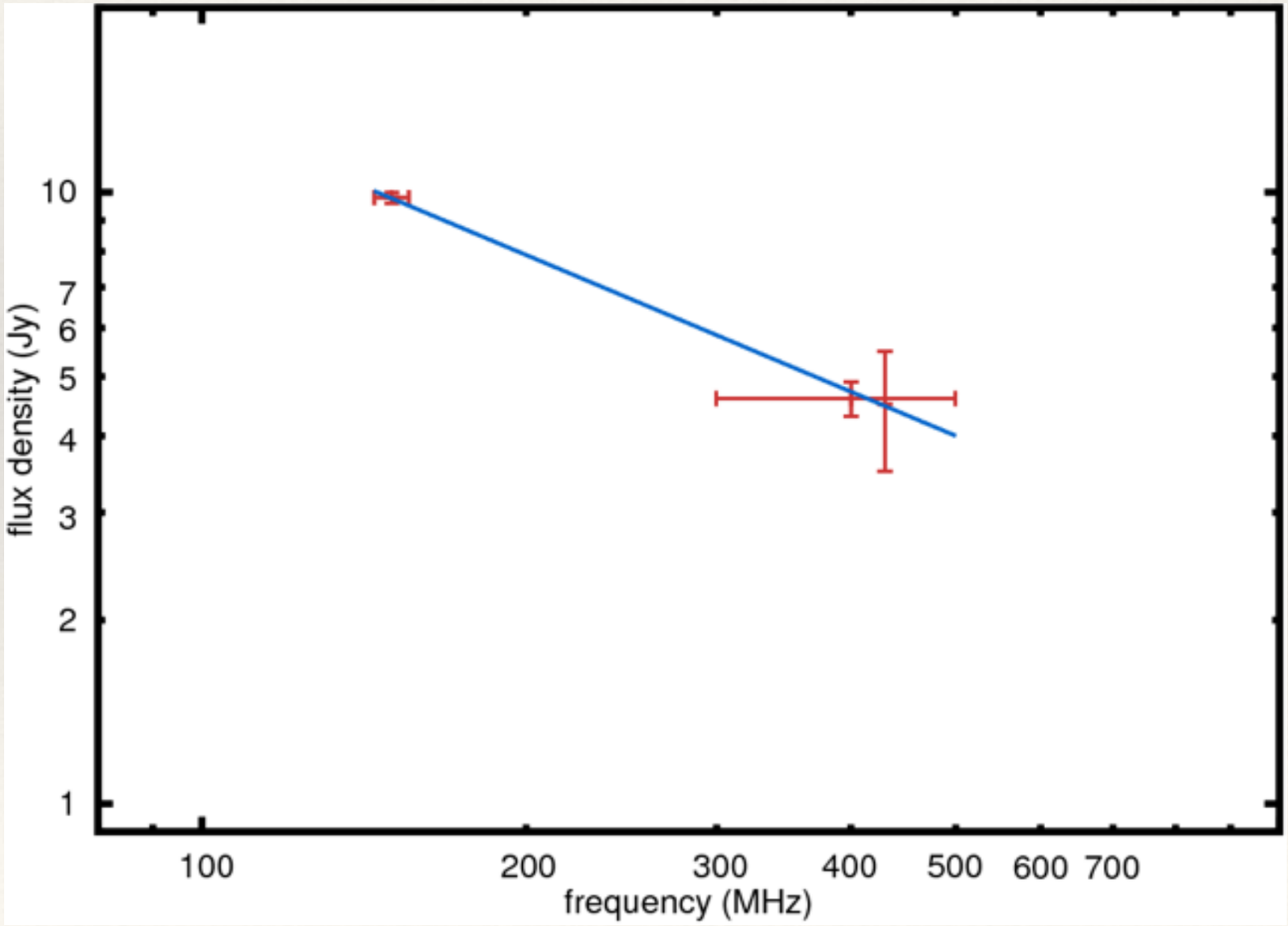
  9.8 +/- 0.3 Jy

  $\alpha_{(408-150)}$ 0.77 +/-0.08

- **250-500 MHz**

  40-50 arcmin extent

  4.6 +/-0.4 Jy



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The story so far | Coma cluster

A high resolution, high sensitivity, low radio frequency view of the Coma cluster

Deepest and high dynamic range images

A clear detection of Coma halo emission at several radio frequencies

direction-dependent errors

antenna pointing errors

variation of amplitude/phase within the primary beam

atmosphere phase gradients

… (talk by Ishwara-Chandra C.H.)

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Imaging using uGMRT

With the new capabilities of the upgraded GMRT

full frequency coverage across several bands

from 2048 to 16348 frequency channels

dual polarisation

raw data occupies ~90GB (5.3 sec, 30 ant, 2 pol, 2k ch, 7.5 hr)

Imaging challenges

We need fast efficient, 'correct', easy-to-use deconvolution

…

Much work lies ahead to understand / control these

(early 'Science Verification' results from uGMRT were encouraging and there are loads of regular uGMRT proposals)

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